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# Optimization of Pre- and Post-Dispersion Compensation Schemes for 10-Gbits/s NRZ Links Using Standard and Dispersion Compensating Fibers

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**Abstract**—We perform a systematic numerical optimization of pre- and post-compensation normalized sections using standard and dispersion compensating fibers for non-return to zero 10-Gbits/s single channel systems. By independently varying the power at the different types of fibers inputs and the compensation ratio, we find that post-compensation performs better than precompensation at the expense of stricter parameter tolerance. Moreover, we show that both pre- and post-compensated systems can be significantly improved by using passive predistortion at the transmitter.

**Index Terms**—Dispersion compensation, optical fiber communication, optical fiber nonlinearity, optical networks.

## I. INTRODUCTION

THE USE OF dispersion compensating fiber (DCF) is an efficient way to upgrade installed links made of standard single mode fiber (SMF) [1]. It has also been suggested that the design of future optical transparent networks could be facilitated by the use of so-called “normalized sections” [2], [3]. Any path through the network would then consist of a cascade of identical normalized sections and, therefore, both network scalability and management would rely on the knowledge of the accumulated signal degradation after transmission through a certain number of these sections. Spans made of SMF and DCF are good candidates as their high local dispersion is known to reduce the phase matching giving rise to four-wave mixing in wavelength division multiplexing (WDM) systems. Signal degradation in such systems is due to the combined effects of group velocity dispersion, Kerr nonlinearity, and accumulation of amplified spontaneous emission noise due to periodic amplification. Because of the nonlinear nature of propagation, system performance depends on the power levels at the input of the different types of fibers, on the position of the DCF [4], and on the amount of residual dispersion [5], [6]. Of particular interest are the pre- and post-compensation schemes where each link is made of spans where the DCF is located before or after the SMF, respectively.

In this letter, the cascability of 80-km-long normalized sections using the post- and precompensation schemes is investigated in a systematic fashion using computer simulation

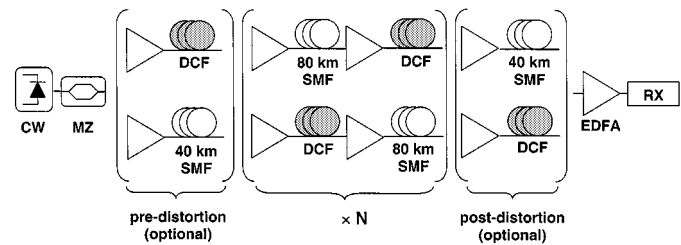


Fig. 1. (top) Post- and (bottom) pre-compensation systems under investigation with and without the optional predistortion fibers.

for single channel non-return to zero (NRZ) modulation at 10 Gbits/s. We add another degree of freedom compared to earlier work [4], [5] by allowing for independent variation of the SMF and DCF input powers in order to define transmission optima and enable a comparison of the different normalized sections. The influence of the compensation ratio defined as the absolute value of the ratio of the total dispersion accumulated in the DCF to the total dispersion accumulated in the SMF for one span is also systematically investigated. We generalize the results of [5] and show that better performance can be obtained for post-compensation provided correct power levels are used at the SMF and DCF inputs. Moreover, we also investigate the influence of predistortion consisting of an added piece of DCF at the transmitter in the post-compensation scheme or a piece of SMF in the precompensation case and corresponding compensation at the receiver. We demonstrate that predistortion can significantly improve the performance of both pre- and post-compensated systems and shifts the optimum power levels toward higher values which, in turn, provides a higher optical signal-to-noise ratio (SNR) throughout the link.

## II. RESULTS AND DISCUSSION

The systems under investigation are shown in Fig. 1. Continuous wave (CW) light is externally modulated at 10 Gbits/s with an NRZ pseudorandom binary sequence in a chirpless Mach-Zehnder modulator having a 13-dB extinction ratio and 25-ps rise time, before being transmitted in a link consisting of a cascade of pre- or post-compensation normalized sections. These sections consist of 80 km of SMF and a variable length of DCF, which is adjusted to define the compensation ratio. The fiber parameters are given in Table I. Two erbium-doped optical fiber amplifiers (EDFA) with 5-dB noise figure are used in each section in order to independently set the SMF and DCF input powers. After a number of cascades, the signal is

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TABLE I  
SMF AND DCF PARAMETERS

	SMF	DCF
Attenuation (dB/km)	0.25	0.5
Dispersion (ps/nm.km)	16	-102
Dispersion Slope (ps/nm <sup>2</sup> .km)	0.06	-0.2
Non-linear index (m <sup>2</sup> /W)	$2.6 \times 10^{-20}$	$2.6 \times 10^{-20}$
Effective Area ( $\mu\text{m}^2$ )	80	22

amplified to a level of 0 dBm, filtered by a first order optical band-pass Gaussian filter with a 3-dB bandwidth of 25 GHz and fed to the receiver, which consists of a PIN photodiode with a responsivity of 1 A/W and a single-sided thermal noise density of 15 pA/ $\sqrt{\text{Hz}}$ , followed by a fifth order low-pass Bessel filter with a 3-dB bandwidth of 10 GHz. Optionally, a piece of DCF (respectively SMF) can be added at the transmitter in the post-compensation (respectively precompensation) case, the dispersion of which is compensated for at the receiver by an additional piece of SMF (respectively DCF). EDFAs are used to exactly compensate for the loss in these pre- and post-distortion fibers.

The calculation of the propagation in the optical fibers was performed using a standard split-step algorithm with adaptive step-size [7]. The EDFAs were modeled by wavelength independent gain and noise addition. Signal and noise interaction was included during propagation in the fibers. Noise was calculated in a 320-GHz bandwidth centered around the transmitter frequency, which is equivalent to the use of a 2.5-nm square band-pass in-line filter. Sequence lengths of 1024 bits were used in order to obtain realistic  $Q$  factor estimations in the receiver model.

For each compensation ratio, the powers at the SMF input and DCF input were varied systematically by setting the gains of the EDFAs, and the  $Q$  factor was calculated for each set of power after a defined number of cascaded spans. Fig. 2 shows  $Q$  factor contour plots obtained after 10, 20, 30, and 40 cascades for 98% post-compensation without any predistortion. The powers displayed on the axes are signal average power, meaning that the noise power in a given bandwidth centered on the laser wavelength is not taken into account. The existence of a transmission optimum for certain sets of powers is clearly seen in these contour plots. This optimum corresponds to input powers of about 2 and -7 dBm into the SMF and DCF, respectively. It can moreover be observed that in this case, the position of the optimum does not vary much when the number of cascaded spans is increased. This allows for flexibility in network design as the power levels can be set independently of the path followed by a signal.

The compensation ratio has been varied between 97% and 101% for both pre- and post-compensation schemes and optimum  $Q$  values and fiber input power levels have been extracted from contour plots similar to the ones in Fig. 2. The results are summarized in Fig. 3, where the maximum  $Q$  factors and the corresponding powers are plotted as a function of the compensation ratio for 30 cascaded sections corresponding to a 2400-km link. Post-compensation shows better performance than precompensation and exhibits a clear optimum

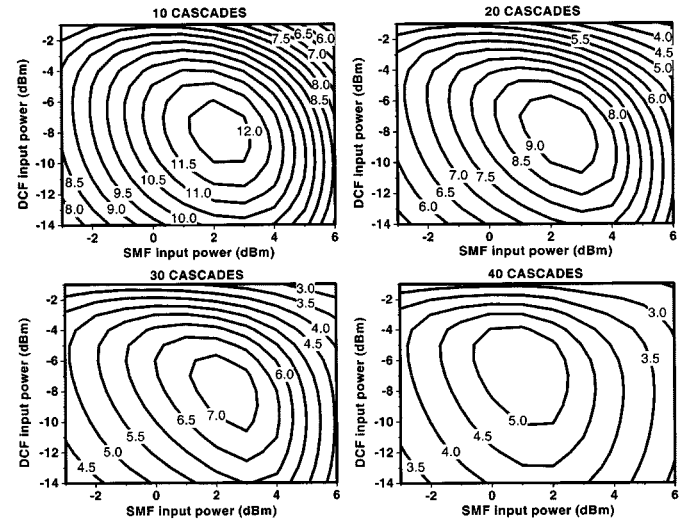


Fig. 2. Evolution of the  $Q$  factor as a function of SMF and DCF input powers for 10, 20, 30, and 40 cascaded sections in the case of 98% post-compensation without predistortion.

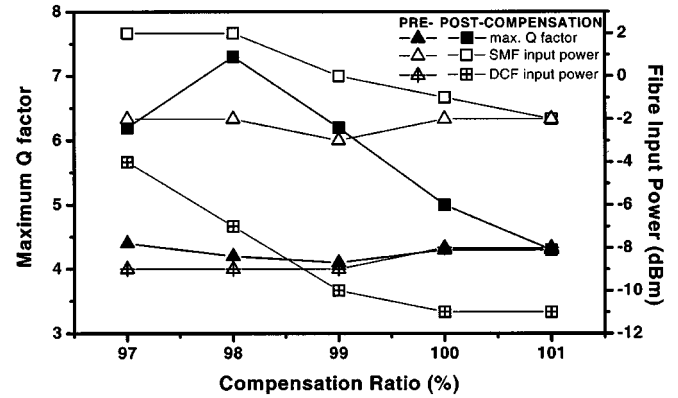


Fig. 3. Maximum  $Q$  factor and corresponding SMF and DCF input powers as a function of the compensation ratio for 30 cascades of the pre- and post-compensation sections.

corresponding to 98%. The  $Q$  factor and optimum power levels vary significantly when the compensation ratio is changed, which is not observed for precompensation showing poorer but more stable performance. It should be pointed out that in our system, a 1% change in the compensation ratio corresponds to only 12.8 ps/nm variation in dispersion, which is a high accuracy requirement when ordering dispersion compensating modules from fiber manufacturers. Moreover, even if we assume that multichannel nonlinear effects have little influence on systems making use of SMF and DCF, and unless DCFs with slope compensation are used, the compensation ratio will vary from one channel to another in WDM systems resulting in unequal channel performance. Therefore, running a system at its maximum performance using post-compensation does not allow for much parameter tolerance.

It can also be seen in Fig. 3 that when the compensation ratio is decreased, optimum powers at both SMF and DCF inputs need to be increased in the post-compensation scheme. For 100% compensation, fiber input power levels are set by SNR requirements and not by the need to counteract dispersion imbalance by self phase modulation (SPM). On the other hand,

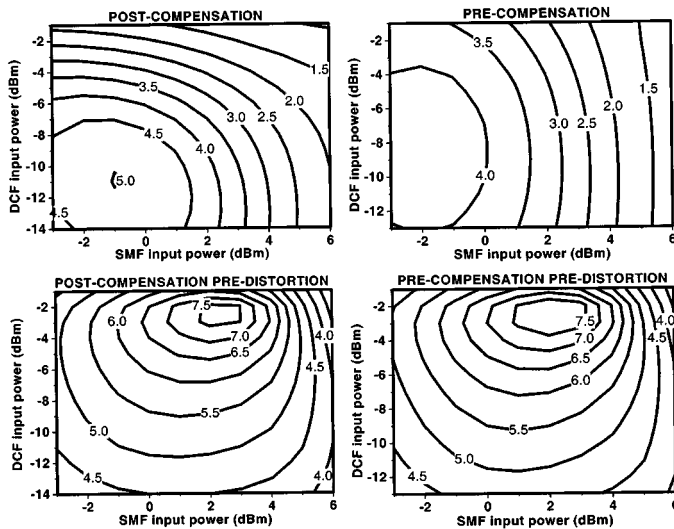


Fig. 4. Q-factor for 30 cascades as a function of SMF and DCF input powers for 100% post- (left) and pre- (right) compensation with (bottom) or without (top) 50% predistortion.

when the compensation ratio is decreased, some amount of SPM is required to make up for the undercompensation. SPM in the anomalous dispersion regime leads to pulse compression [7] and, therefore, a higher power into the SMF is desirable. Fig. 3 shows that some amount of SPM in the DCF can also be beneficial for an undercompensated system, which is in agreement with [6], which studied a single span system.

Introducing a predistortion fiber reduces the maximum amount of total accumulated dispersion and realizes some passive prechirping at the transmitter. In Fig. 4, we show the relative performance of pre- and post-compensation with and without predistortion for 100% compensation and 30 cascades. In this case, the absolute value of the dispersion of both pre- and post-distortion fibers corresponds to half the total dispersion accumulated in one span of SMF. With this value, the excursion (from 0 ps/nm) of the total accumulated dispersion is minimized and is moreover the same for pre- and post-compensation. However, it might not correspond to an absolute optimum as new design parameters (lengths and input powers of pre- and post-distortion fibers) are introduced. Again, a higher maximum  $Q$  factor is obtained for post-compensation compared to precompensation. For a given compensation ratio (here 100%,

but the same trend has been observed for other ratios), the transmission performance can be significantly improved by using predistortion. In the 100% case, results are comparable whether pre- or post-compensation is used. This is due to the fact that in this case, if the pre- and post-distortion fibers are excluded, these two dispersion maps are only translated by one DCF length. predistortion has also the effect of shifting the optimum powers toward higher values. This is beneficial as it provides a higher SNR ratio throughout the system.

### III. CONCLUSION

We have performed a systematic compensation ratio and fiber input power optimization of pre- and post-dispersion compensation schemes using SMF and DCF. We have shown that if no predistortion is used, post-compensation performs better at the expense of more stringent parameter tolerance. A compensation ratio of 98% has been found to constitute an optimum for post-compensation. On the other hand, when precompensation is used, little influence of the compensation ratio on the optimum  $Q$  factor and power levels has been observed. We have also shown that introducing predistortion can significantly improve the performance of both pre- and post-compensation schemes.

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